Full Annual Report: Crop year 2016

Using Heat Unit to Predict Pistachio Maturity and Size

Lu Zhang, Narges Moosavi Mahvelati, Cara Allan and Louise Ferguson
Department of Plant Sciences, University of California Davis CA 95616
LFerguson@ucdavis.edu Phone # 559-737-3061

Summary:

A pistachio nut growth model was developed to describe the three growth stages of a pistachio fruit; pericarp growth, shell hardening and embryo development, as a function of heat units for the Kerman, Lost Hills, Golden Hills, Kaleghouchi and Pete 1 cultivars. The purpose of building this heat-based model is to predict the critical growth stages to facilitate pest management, irrigation scheduling and optimal harvest date. The three stages were measured weekly starting with bloom and ending with harvest through the 2014 and 2016 seasons. Hourly temperatures were monitored in each location and the thermal unit accumulation was calculated with the base temperature of 7°C. The selfStart non-linear asymptotic growth model fit by the maximum likelihood method was coded in the R Statistics program. The results proved the current sampling data fit the model well and the predicted values of the dimensions were uniform between the two years. Using this model, the three nut growth stages can be predicted based on local heat accumulation by applying the prediction curve.

Background and Significance:

Pistachio nut growth has 3 stages: 1) the pericarp (shell = endocarp, hull = exocarp) expansion growth that produces the final in-shell nut size; 2) the thickening and hardening of the pistachio endocarp (shell) which is a process of lignification; 3) embryo (kernel) growth (Crane, 1981; Goldhamer, 2004).

It has been reported that the water requirements of pistachio change through the growth season. Pericarp expansion (stage 1), requires full ET for maximum growth (Ferguson, 2005). Shell hardening (stage 2) requires less water. Goldhamer (2004) demonstrated that 50% deficit irrigation during stage 2, before embryos initiate expansion will not affect the nut quality. But the later kernel growth (stage 3) involving embryo growth requires full ET. Therefore, precise prediction of each stage will assist growers with irrigation scheduling and efficiency. Management of *Calocoris* and *Lygus*, insects that can deform young nuts before shell hardening, would be greatly facilitated by the ability to predict when control was no longer necessary. The model developed in this study will facilitate predicting when growers can cease prophylactic pest control for insects that cannot pierce a hard shell.

Generally, for nut crops, a poorly timed harvest can decrease yield and quality and increase the possibility of navel orangeworm infestation. The ability to predict the optimal harvest date would be a useful tool. The ultimate aim of this study is to produce a model that precisely predicts the nut growth and maturity as a function of heat unit accumulation converted to calendar date.

Objectives:

The 2016 objectives were:

1) Weekly data collection on the 5 cultivar at 6 locations.

2) Improve and verify the prediction model.

Materials and Methods:

The nut growth of five cultivars, i.e. Kerman, Lost Hills, Golden Hills, Kaleghouchi and Pete 1 from six locations Lost Hills (Kern County), Parlier (Fresno County), Mendota (Fresno County), Porterville (Tulare County), Le Grand (Merced County) and Arbuckle (Colusa County) was monitored through the growing season. Sampling was done weekly from fruit set through harvest, April to September. Twelve clusters were collected from three marked trees in each location. Bloom date, percentage set, endocarp and embryo growth (height, length, width, volume), shell hardness, fresh and dry weight and yield and CPC grade were measured and recorded.

Hourly temperatures were collected by data loggers (Onset HOBO® U23-001 Pro v2 Temperature/ RH Data Loggers) installed at each location and housed in a UV protective shield (Onset HOBO® Solar Radiation Shield). The thermal units were determined by taking daily average and removing the base temperature of 7 ℃.

The *SSasymp*, a non-linear asymptotic function was used to predict pistachio nut growth based on heat unit accumulation, analyzed with the R Statistics program. This function is appropriate for the prediction of the fruit growth as the relative growth rate is initially rapid and then slows (Paine, 2012). The rapid expansion rate of pistachio shells at the beginning of each growth stage has been described (Bentley, 1999; Ferguson, 2005), and matches the description and requirements of this model function well. This function is defined by the three parameters given below:

(1) the maximum nut growth value NG_{max}, which is equivalent to the asymptote of the curve,
(2) the highest rate constant (k), that is the speed to reach the maximum nut growth value,
(3) r is the offset value of heat units, and with this input the response – the nut growth value is zero.

The parameters in the model are estimated by the maximum likelihood method.

$$NG_x = NG_{max} * (1\text{-esp} (- \text{esp} (k) * (\text{input} - r)))$$

Results:

The comparison of the thermal unit accumulation and nut growth between the same calendar days of 2014 and 2016 demonstrated that nut growth was more strongly correlated with heat accumulation than date. On Aug 18, the thermal unit by Kerman was 2202 with predicted nut volume at 3327 mm^3 in year 2014. In 2016 the heat unit accumulation was 1985 and volume was 3052 mm^3. This demonstrates accuracy of using heat unit accumulation rather than calendar date.

The determination coefficient (r^2) between the predicted and actual values of the three investigated indexes for nut growth were all beyond 0.85 (the usual acceptable value of correlation is 0.75) demonstrating that the current sampling data fit the growth model well. In addition, the plotted actual data (pink dots) and predicted data (black dots) evenly distributed well. Further, the standard errors of estimated parameters were small. Based on these estimates, the predicted curves rarely varied, see the grey shadows in the graphs (Fig. 1), that proved again that the pistachio nut growth value fit this function well. In future analyses comparisons of this *SSasymp* – monomolecular model, other asymptotic model functions such as *SSlogis* – the three parameters logistic model, *SSfpl*, and the four parameters logistic model will also be used to predict the nut growth (Paine, 2012).

<u>Stage 1. Nut (pericarp) expansion growth</u>

The pericarp consists of the pistachio shell and its fleshy hull, collectively the pericarp, referred to as the nutshell. Relative to the other four cultivars, the Pete 1 cultivar has the largest shell, 3716 mm^3. However, initially, at 500 TU, Pete 1 was smaller. That is, between 300-1000 TU, the shell volume of Pete 1 increased by ca. 2600 mm^3 while the volume of other four cultivars increased only by 1500-1800 mm^3. This may be among the reasons Pete 1, with its extremely high percentage of partially filled nuts was not a successful cultivar. It requires very high heat units to successfully fill its larger shell.

<u>Stage 2. Endocarp (shell) hardening</u>

The predicted maximum values of shell firmness in Kerman, Lost Hills, Golden Hills, Kaleghouchi and Pete 1 were 26.63, 23.84, 24.74, 23.37 and 23.90 lb/3mm^2, respectively. However, unlike earlier research suggesting the shell lignification was fully completed after shell growth was completed and before kernel (embryo) growth initiation, our results demonstrated the shell was still thickening and hardening after the embryo began growing. And, as the curve of hardening did not reach a maximum value by harvest the shell appeared to be continuing to harden at harvest (Fig.1, b). Interestingly, among the five cultivars the predicted values rarely varied between years but were different among cultivars (Table 1). For example, the hardness of Pete

1 at 1000, 1500 and 2000 TU was 14.0 ±0.5, 18.7 ± 0.2 and 21.3 ± 0.2 lb/3mm^2 varied among years and, but among cultivars the differences in firmness were smaller, between 1.5-4 lb/3mm^2.

3. Embryo development

The predicted maximum asymptotic values of embryo length were 20.08, 22.10, 19.80, 19.76 and 20.81mm in Kerman, Lost Hills, Golden Hills, Kaleghouchi and Pete 1 pistachios, respectively. The embryo started growing at approximately 1000 TU and reached maximum size at approximately 2200 TU in all five cultivars (Fig.1, c).

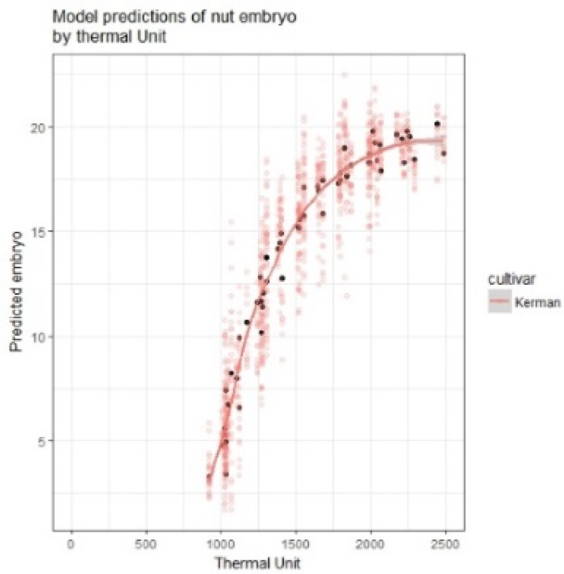
It is interesting that the cultivar Pete 1, with the largest shell, had a kernel no longer than the other two cultivars. It could be that the kernels of Pete 1 were wider than kernels of other cultivars, therefore, the model prediction for the embryo volume is necessary in future work.

Conclusion and Practical Applications

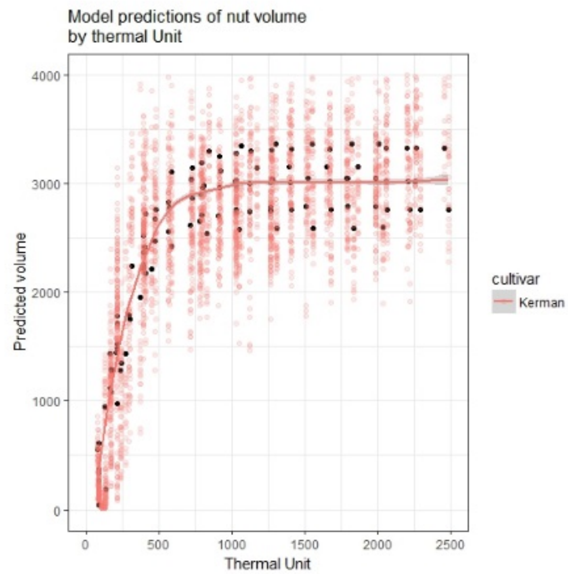
The predicted values of nut volume, shell firmness and kernel length were uniform between the two years, but the variations among cultivars were obvious. Using this model, the three nut growth stages can be predicted based on heat unit accumulation by applying the prediction curve (e.g. Fig.1). Our final objective is development of a model that predicts the number of heat units required to complete all three growth stages in the Kerman, Lost Hills, Golden Hills, Kaleghouchi and Pete1 cultivars and to develop the software to convert thermal units to calendar date (based on historical temperature records), that will predict optimal harvest date based on kernel growth. The 2017 data should give us the information we need to complete this project.

Table 1. Predicted shell firmness at 1000, 1500 and 2000 thermal unit in Kerman, Lost Hills and Pete 1 pistachios based on the data of 2014, 2016 and the two-year combination. (unit: lb/3mm^2).

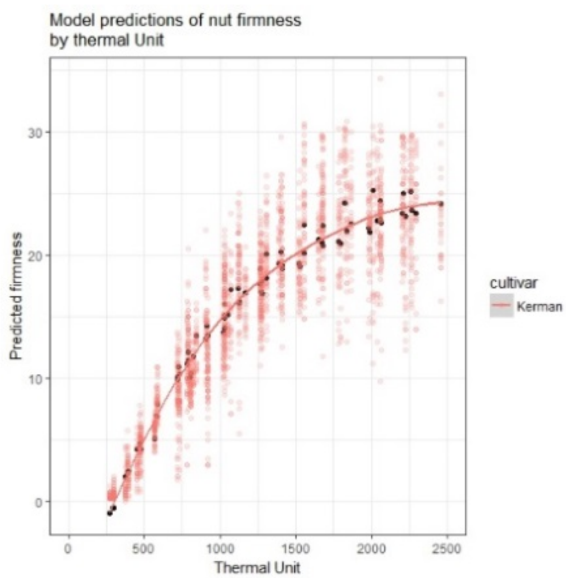
Thermal Units	Kerman			Lost Hills			Pete 1		
	2014	2016	2014+2016	2014	2016	2014+2016	2014	2016	2014+2016
1000	15.23	15.23	15.23	12.21	11.25	11.47	14.44	13.92	14.44
1500	20.01	20.01	20.01	16.65	16.25	16.65	18.66	18.64	18.88
2000	22.62	24.36	23.93	19.61	20.00	19.98	21.48	21.12	21.48



(a)

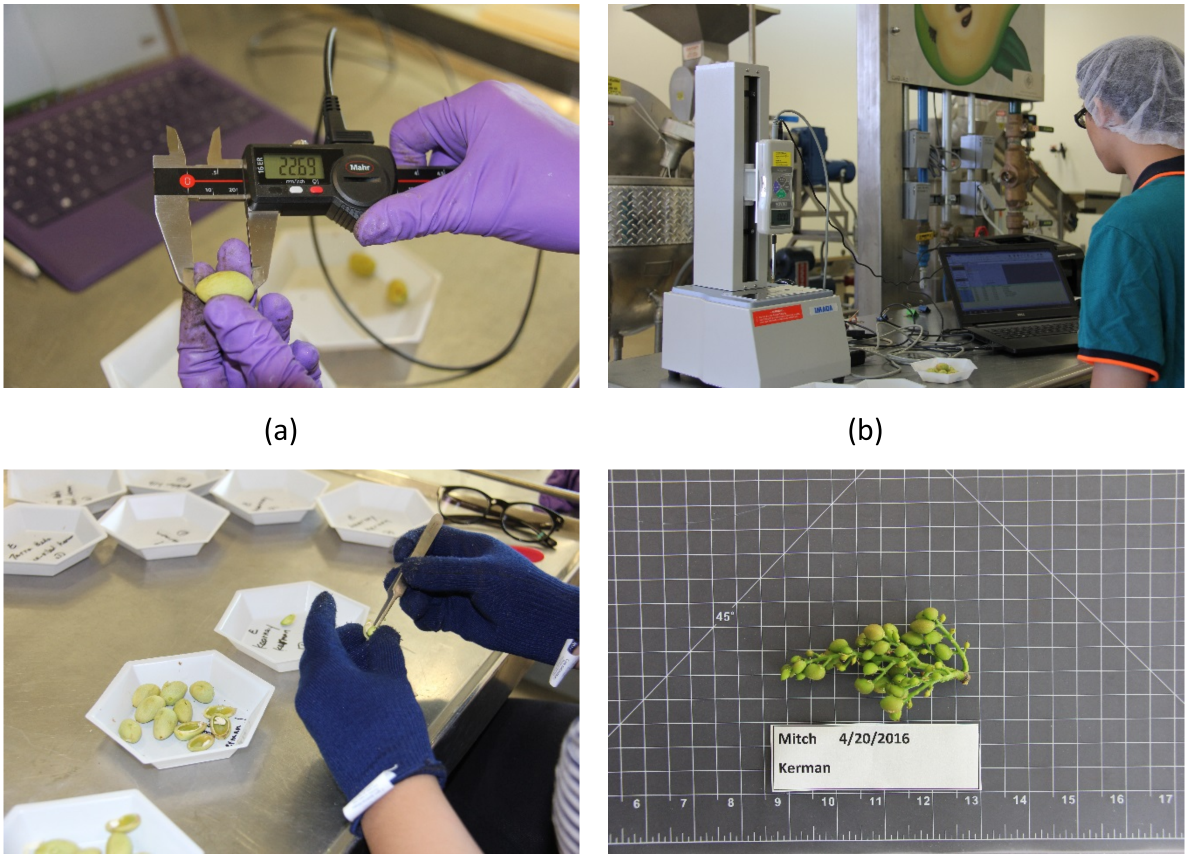


(b)



(c)

Fig 1. Model prediction of nut volume (a), shell firmness (b) and kernel length (c) in Kerman based on 2014 and 2016 data. The red curve is the model's mean predicted value, the grey shadow is the variability among the data called standard error, the black dots are the predicted values and pink dots are the actual value.



(a) (b)

(c) (d)

Fig 2. Nut measurements in the laboratory. (a) Measuring the length, width and height of nuts by using a caliper; (b) Testing the shell hardening by using a penetrometer; (c) Separating hulls and kernels and measuring the embryo length; (d) Pictures recording the nuts development in each sampling locations.

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